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FINAL SUMMARY REPORT

CARGO AIRCRAFT MINELAYING (CAML) SYSTEM ENGINEERING SUPPORT FOR ADVANCED DEVELOPMENT EFFORT

December 1981

Prepared for
CAML TECHNICAL DEVELOPMENT MANAGER
NAVAL SURFACE WEAPONS CENTER, WHITE OAK
SILVER SPRING, MARYLAND
under Contract N60921-80-C-0155

ARINC RESEARCH CORPORATION

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December 1981

by

C. J. Frampton

Prepared for

CAML Technical Development Manager
Naval Surface Weapons Center, White Oak
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This report summarizes the work accomplished by ARINC Research Corporation to provide engineering support for the Cargo Aircraft Minelaying (CAML) System Advanced Development effort. The work included reliability, maintainability, and cost analysis.

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ABSTRACT

This report summarizes the work accomplished by ARINC Research Corporation to provide engineering support for the Cargo Aircraft Minelaying (CAML) System Advanced Development effort. The work included reliability, maintainability, and cost analysis. It was performed from 7 April 1980 through 31 December 1981 under Contract N60921-80-C-0155 with the Naval Surface Weapons Center, White Oak (NSWC/WO), Silver Spring, Maryland (Code U32).

SUMMARY

Under Contract N60921-80-C-0155, ARINC Research Corporation provided reliability, maintainability, and cost analysis of the Cargo Aircraft Minelaying (CAML) Advanced Development System. The period of performance of the contract was from April 1980 through December 1981. The effort included four tasks.

Task 1 encompassed the review of Lockheed-Georgia reliability, maintainability, and cost deliverables for the CAML contract (N60921-80-C-0023). The deliverables were compared with similar deliverables for other successful mine programs on the basis of ARINC Research Corporation's previous experience in program reliability, maintainability, and cost monitoring.

Task 2 was a cost analysis of the CAML system. We assisted in the development of the CAML life-cycle-cost estimates by developing cost methodology, collecting pertinent cost data, analyzing the data, identifying problem areas and additional data requirements, and establishing an acquisition-cost estimate.

Task 3 included reliability, maintainability, and cost evaluations for the CAML design. We also evaluated the CAML design for conformance to specified plans and programs. We attended formal design reviews; reviewed drawings; reviewed parts applications; and performed reliability, maintainability, and cost analyses as required to assess program progress and conformance to requirements.

Task 4 consisted of the development of recommended reliability, maintainability, and cost requirements for the upcoming CAML Engineering Development phase. This work was accomplished in accordance with established doctrine that has been used successfully for previous development contracts of similar complexity and scope. The recommended reliability requirements are generally based on MIL-STD-785; they include a reliability demonstration test based on MIL-STD-781. Maintainability requirements are generally based on MIL-STD-470; they include a maintainability demonstration test based on MIL-STD-471. Cost requirements are based on Department of Defense (DoD) Directives 5000.1 and 5000.2. In addition, all requirements are based on the CAML design capability established during the Advanced Development phase.

Funding support for the CAML program was reduced in March 1981. As a result of the funding constraints, Lockheed-Georgia's R&M efforts were significantly delayed and reduced, and our contractual effort was also affected. Our reporting requirements were modified by the NSWC/WO technical development manager (TDM), who also directed us to concentrate our efforts on monitoring the reliability aspects of the CAML design.

The following conclusions and recommendations are based on our analysis and support efforts:

- Although Lockheed-Georgia has been responsive to comments resulting from our review of their deliverable items, they do not have a complete understanding of all Navy R&M requirements. Therefore, we recommend that their efforts be monitored during CAML Full-Scale Engineering Development (FSED).
- Since all Lockheed-Georgia R&M and cost analysis deliverables were not available for review during the contract period, because of the program funding reductions, considerable additional effort will be required to develop acceptable cost models and to provide design and program guidance during FSED. We recommend that the cost analysis effort be initiated in the early phases of FSED to provide the data required for subsequent design and program decisions.
- The present CAML Advanced Development design is capable of meeting specified R&M requirements; however, the CAML system has shown considerable cost growth. Some alternative design concepts proposed by Lockheed-Georgia offer significant improvement in R&M and LCC areas; therefore, we recommend that the alternative design concepts be given serious consideration.
- Although the current Advanced Development design FSED requirements are adequately defined and documented, expected major design changes and existing program funding constraints may make significant changes necessary. To minimize the document development time, we recommend that Navy personnel who participated in or are familiar with earlier CAML efforts be assigned to future FSED efforts and associated preparation activities if program funding is restored.

CONTENTS

CONTENTS (continued)

CHAPTER ONE

INTRODUCTION

This report summarizes the work performed by ARINC Research Corporation to provide engineering support for the Cargo Aircraft Minelaying (CAML) System Advanced Development effort. The work was performed for the Naval Surface Weapons Center, White Oak (NSWC/WO), Silver Spring, Maryland (Code U32) from 7 April 1980 through 31 December 1981 under Contract N60921-80-C-0155. The tasks and deliverable items specified in the contract are described in the following sections.

1.1 CONTRACT TASKS

1.1.1 Task 1: Review Development Contractor Deliverable Items

The contractor shall review the following data items that are deliverables from the development contractor (the Lockheed-Georgia Company) under contract number N60921-80-C-0023.

a. A010 - Reliability Test Plan

b. A011 - Maintainability Demonstration Plan

c. A012 - Report, Reliability and Maintainability (R&M) Allocations, Assessments, and Analysis

d. A013 - Reports, Maintainability Analysis and Prediction

e. A014 - Reliability Program Plan

f. A015 - Maintainability Program Plan

g. A019 - Report, Reliability Prediction

h. A021 - Reliability, Maintainability and Safety Program Plan (R&M aspects only)

i. A025 - Preliminary Cost Model (updates only)

j. A026 - Final Production Cost and Life Cycle Cost (LCC) Model

k. A028 - Monthly Technical Progress Reports (R&M- and LCC-related factors only)

l. A029 - Milestone Reports (R&M- and LCC-related factors only)

m. A030 - Final Report (R&M- and LCC-related factors only)

The contractor shall prepare a written critique of each of the above-listed Lockheed-Georgia data items and submit them to the Navy as defined in data item A001. The critiques shall include, as applicable: identification of problem areas, recommendations for changes/improvements, clarifications, and other pertinent information. Also, when updates to the above-listed Lockheed-Georgia information are provided, corresponding updates to the contractor critique shall be submitted under data item A001 herein.

1.1.2 Task 2: Perform Life-Cycle-Cost Analysis

The contractor shall perform LCC analysis in support of the CAML program. This shall consist of the following functions:

a. Development of the elements and structure of the cost model

b. Collection of data for the model from the Navy, the development contractor, and other pertinent sources

c. Analysis of the data

d. Identification of cost data problem areas and/or additional data requirements

e. Establishment of LCC estimate

The above functions shall be performed in cooperation with the Navy and the development contractor so as to minimize duplication of effort or loss of coordination. Status reports on this effort shall be provided in the quarterly progress reports (data item A002). The completed effort shall be reported in data item A004.

1.1.3 Task 3: Evaluate R&M and LCC Aspects of the CAML System Design

The contractor shall evaluate the design of the CAML system presented by the development contractor and its subcontractors/vendors in the following areas:

a. Conformance of the system to R&M requirements

b. Soundness of the design approach from the standpoint of R&M

c. Conformance of the system to design-to-cost goals

d. Soundness of the design approach from the standpoint of cost-effectiveness. The contractor shall perform cost/performance trade-off analyses as required in support of this task.

In addition, the contractor shall evaluate the performance of the development contractor and his subcontractors/vendors in the following areas:

a. Understanding of and conformance to R&M plans and programs

b. Understanding of and performance in the application of cost analysis techniques in the development of the CAML system

The above efforts shall be ongoing, and status reports shall be included in data item A002. The contractor shall participate in the formal review of the CAML system design that is required of the development contractor and make a written report to the Navy per data item A003 that includes pertinent comments, identification of problem areas, strong and weak points, recommendations, etc. A similar write-up that updates the above report shall be included in data item A004.

1.1.4 Task 4: Develop CAML Reliability, Maintainability, and Cost Analysis Requirements for Full-Scale Development

The contractor shall develop and propose system and program requirements for the CAML Full-Scale Engineering Development effort in the areas of R&M and LCC analysis. The results of this effort shall be included in data item A004.

1.2 CONTRACT DELIVERABLE ITEMS

The contract specified four deliverable items:

- Data Item A001 - Milestone reports (informal) to be delivered 30 days after receipt of government information (Task 1)
- Data Item A002 - Quarterly Technical Progress Reports (informal) (Tasks 2 and 3)
- Data Item A003 - Report of Design Review (informal) to be delivered 30 days after the development contractor's formal design review (Task 3)
- Data Item A004 - Final Summary Report (Tasks 2, 3, and 4)

1.3 ADDITIONAL TECHNICAL DIRECTION

Funding support for the CAML program was reduced in March 1981. As a result of the funding constraints, Lockheed-Georgia's R&M efforts were significantly delayed and reduced. Although our contract funds were not reduced, our contractual effort was also affected by the reduction in overall program funding. After the CAML program was reduced, the NSWL/WO technical development manager (TDM) redirected our contractual efforts within the remaining contract funding. This was required to parallel Lockheed-Georgia's efforts and to provide the most essential services for the remaining CAML program period. The TDM directed us to report subsequent document reviews formally in our quarterly status letters and this final report, and informally through continuing progress reviews held with cognizant NSWC/WO personnel. We were also directed to concentrate our efforts on monitoring reliability aspects of the CAML design.

CHAPTER TWO

REVIEW OF CONTRACTUAL EFFORTS

This chapter describes the work that we performed under each of the four contract tasks. Deliverable items and task activities, together with results, conclusions, and recommendations, are summarized in the following sections.

2.1 SUMMARY OF CONTRACT DELIVERABLES

2.1.1 Reviews of Lockheed-Georgia Deliverable Items

The following Milestone Reports (data item A001) on the review of the Lockheed-Georgia data items were delivered as indicated (ARINC Research Corporation letter serial and date):

- Milestone Report, Lockheed-Georgia deliverables A012, A021, A028 (SEP/S&O/80-084 of 21 July 1980)
- Milestone Report, Lockheed-Georgia deliverable A028 (SEP/S&O/80-106 of 11 August 1980)
- Milestone Report, Lockheed-Georgia deliverables A013, A019, A028 (SEP/S&O/80-143 of 4 December 1980

As directed by the NSWC/WO TDM, reviews of other Lockheed-Georgia deliverables were reported in Quarterly Technical Progress Reports (data item A002). The following quarterly status letters included review reports for the identified Lockheed-Georgia data items (ARINC Research Corporation letter serial and date):

- Fourth Quarterly Status Letter: (SEP/S&O/81-047 of 23 April 1981) Lockheed-Georgia deliverables A018,* A028
- Fifth Quarterly Status Letter: (SEP/S&O/81-087 of 20 July 1981) Lockheed-Georgia deliverable A028

*Reviewed at the direction of the TDM, although not specified in the contract.

* Sixth Quarterly Status Letter:
  (SEP/S&O/81-114 of 15 October 1981) Lockheed-Georgia deliverable A028

Additional Lockheed-Georgia deliverables -- A028, A010, and A014 -- were received by ARINC Research subsequent to the last quarterly status report. Their review is documented in this final summary report.

Lockheed-Georgia deliverables A011, A015, A025, A026, A029, and A030 were not available for review during the contract period.

Appendix A presents the Milestone Reports delivered as data item A001. Appendix B presents review comments extracted from the Fourth, Fifth, and Sixth Quarterly Status Letters. Appendix C presents detailed review comments on the remaining Lockheed-Georgia deliverables received subsequent to submittal of the Sixth Quarterly Status Letter.

2.1.2 Quarterly Technical Progress Reports

In addition to the Fourth, Fifth, and Sixth Quarterly Status Letters identified in Section 2.1.1, the following Quarterly Status Letters, representing data item A002, were delivered as indicated (ARINC Research Corporation letter serial and date):

* First Quarterly Status Letter (SEP/S&O/80-075 of 15 July 1980)
* Second Quarterly Status Letter (SEP/S&O/80-136 of 15 October 1980)
* Third Quarterly Status Letter (SEP/S&O/81-015 of 15 January 1981)

Appendix D provides cost analyses extracted from the quarterly status letters.

2.1.3 Report of Design Review

The Report of Design Review, representing data item A003, is provided in Appendix E.

2.1.4 Final Summary Report

This Final Summary Report, representing data item A004, consolidates the information delivered in the quarterly status reports and includes other information developed during the contractual effort. Resource expenditure information for the contract period is provided in Appendix F.

Previously delivered information has been edited for inclusion in the appendixes of this report. A summary of the work accomplished for each contract task and the conlusions and recommendations resulting from the effort are provided in the following sections.

2.2 TASK 1: REVIEW DEVELOPMENT CONTRACTOR DELIVERABLE ITEMS

We reviewed all of the Lockheed-Georgia documents (data items under Contract N60921-80-1-0023) provided during the contract period. Detailed review comments are presented in Appendixes A (data items A012, A013, AC19, A021, and A028), B (data items A018 and A028), and C (data items A010, A014, and A028). Specific activities, results, conclusions, and recommendations for Task 1 are discussed in the following sections.

2.2.1 Task 1 Activities and Results

During April through June 1980, we reviewed the following Lockheed-Georgia data items:

- A012 - Report LG80ER0079, Reliability and Maintainability Allocations, Assessments, and Analysis, dated 28 April 1980 and revised report dated 12 June 1980
- A021 - Report LG800ER0031, Reliability, Maintainability, and Safety Program Plan, dated 29 January 1980, revised 28 March 1980

As a result of the review of the CAML Reliability and Maintainability Allocations and Analysis document (A012), NSWC/WO and ARINC Research agreed that the reliability allocation in the document was unacceptable. As directed, we discussed the problem areas with Lockheed-Georgia during meetings held on 29 May 1980 in Marietta, Georgia. Results of the meetings were reviewed with NSWC/WO on 30 May 1980. As a result of the meetings, Lockheed-Georgia revised and resubmitted data item A012 in June 1980. This submittal was acceptable.

As a result of the review of the updated Reliability, Maintainability, and Safety Program Plan (A021), it was determined that comments and recommendations that we supplied to the Navy during a previous review under Contract N00024-80-C-6078 had been incorporated by Lockheed-Georgia into the plan. No further action was required.

From July through September 1980, we reviewed data item A028 - Monthly Technical Progress Reports dated April, May, and June 1980. The progress reports were considered acceptable in their coverage of R&M and LCC events.

From October through December 1980, we reviewed the following Lockheed-Georgia data items:

- A013 - Report LG80ER0176, Maintainability Analysis and Prediction, dated October 1980
- A019 - Report LG80ER0172, Reliability Prediction, dated 10 October 1980
- A028 - Monthly Technical Progress Reports, dated July, August, September, October 1980

Our review of the R&M prediction reports (A013 and A019) indicated that both were acceptable. Both reports had minor deficiencies, but revision at that time was not advisable, since a proposed major change in the CAML system design would require a complete update of the R&M predictions. Lockheed-Georgia was provided copies of our review comments and agreed to incorporate corrections in the updated predictions. The progress reports (A028) were considered acceptable in their coverage of R&M and LCC events.

From January through March 1981, we reviewed the following Lockheed-Georgia data items:

- A018 - Report LG81ER0067, Failure Mode, Effects and Criticality Analysis, dated 17 December 1980
- A028 - Monthly Technical Progress Reports dated November and December 1980, and January and February 1981

The review resulted in acceptance of the above Lockheed-Georgia deliverables.

From April through June 1981, we reviewed data item A028 - Monthly Technical Progress Reports dated March, April, and May 1981. The progress reports were considered acceptable in content and coverage of R&M and LCC events.

From July through September 1981, we reviewed data item A028 - Monthly Technical Progress Reports, dated June and July 1981. The progress reports were considered acceptable in content and coverage of R&M and LCC events.

From October through December 1981, we reviewed the following additional Lockheed-Georgia deliverable items:

- A028 - Monthly Technical Progress Reports dated August, September, and October 1981
- A010 - Report LG81ER0232, CAML System Full-Scale Engineering Development Reliability Test Plan, dated 26 October 1981
- A014 - Report LG81ER0231, CAML System Full-Scale Engineering Development Reliability Program Plan, dated 26 October 1981

The monthly reports (A028) are considered acceptable in their content and coverage of R&M and LCC events. The reliability test plan (A010) and the reliability program plan (A014) are not considered acceptable for Full-Scale Engineering Development (FSED). The reliability test plans major deficiencies include the omission of any reference to a detailed test procedure and inadequate discussion of allowable maintenance during test. The reliability program plan's major deficiencies include the omission of a manpower budget and insufficient discussion of reliability analysis. Detailed comments on the test plan and program plan are provided in Appendix C.

Additional communication with Lockheed-Georgia will be required during CAML FSED to assure clarification and revision of the reliability test and program plans.

2.2.2 Task 1 Conclusions and Recommendations

Review of the Lockheed-Georgia deliverables indicates that their R&M and design organizations have demonstrated an intent to develop a reliable and maintainable CAML system. Problems have been resolved efficiently through coordinated Navy and Lockheed-Georgia efforts. However, Lockheed-Georgia does not have a complete understanding of all requirements. Many specific recommendations to satisfy Navy R&M requirements have been made by ARINC Research as documented by the review comments provided in Appendixes A, B, and C. Therefore, we conclude that Lockheed-Georgia will require additional R&M guidance and should be monitored during CAML FSED.

Cost-analysis data deliverables were not available for review during the contract period, because of the reductions imposed on the CAML program. Considerable effort will be required to develop acceptable cost-model accuracy to provide design and program guidance during FSED. We recommend that the cost analysis effort be initiated in the early phases of FSED to provide the data required for subsequent design and program decisions.

2.3 TASK 2: PERFORM LIFE-CYCLE-COST ANALYSIS

Under a previous contract (N00024-80-C-6078), we submitted a report on the estimated CAML acquisition cost.* Task 2 of this contract is an extension of the previous effort. Specific activities, results, conclusions, and recommendations for Task 2 are discussed in the following sections.

2.3.1 Task 2 Activities and Results

Our previous acquisition-cost report identified a number of major cost drivers and provided recommendations for possible cost reductions. In July 1980 Lockheed-Georgia conducted a more detailed evaluation of one cost driver, the control/power (C/P) pallet electrical fabrication, and substantially reduced the required man-hours. We prepared an update to the acquisition-cost report to reflect the subsequent 8 percent reduction in total CAML acquisition cost. This update is provided in Appendix D.

As the CAML design matured, changes that had a very significant impact on projected production cost occurred. During July through September 1980, we compared the 1979 design with the 1980 configuration. This comparison indicated that the SPECO drive system had become more complex and expensive.

*ARINC Research Publication 1672-02-1-2185, *An Analysis of the Preliminary Acquisition Cost of the Cargo Aircraft Minelaying (CAML) System (U)*, April 1980 (Confidential).

The SPECO proposal of 15 May 1979 quoted a cost of $373,012 for the CAML recurring development hardware. The proposal of 23 July 1980 quoted a cost of $782,940 for the revised configuration. This 110 percent increase in Advanced Development (ADM) cost will result in a higher production cost.

As of September 1980, production costs for the new drive system had not been provided by Lockheed-Georgia. To obtain a better understanding of the cost change, we compared the SPECO parts in the 1979 configuration with those in the 1980 configuration. We used the costs quoted for each part to determine the cost of the drive system in the CAML launcher, ejector, C/P pallet, and cradle. The part and cost data for the 1979 and 1980 configurations are presented in Tables 2-1 and 2-2, respectively. These tables highlight the increase in both complexity and cost.

During September 1980 Lockheed-Georgia attempted to develop the average unit recurring production costs for these parts. The costs will be significantly lower than shown in Table 2, for two reasons: (1) costs will decrease because of a larger production volume and the effects of learning; (2) the quoted costs were based on the use of the older, less sophisticated, SPECO machinery, while SPECO's newer, numerically controlled equipment will reduce the required man-hours and the resulting production cost.

From October through December 1980 we participated in a CAML Integrated Logistic Support Management Team (ILSMT) review at NSWC/WO. We participated to determine the status of logistic support activities that will contribute to the CAML life-cycle-cost program estimating process. In addition, we began an investigation of LCC elements that require input from the ILS support activities and defined those elements.

During January and February 1981 we continued the investigation and definition of LCC elements that require input from the ILS support activities. We were starting to develop revised acquisition cost estimates on the basis of the updated drive system cost when, on 4 March 1981, we were notified that the CAML program was eliminated from the (POM) budget for fiscal year 1982 and beyond. We were directed to stop any significant cost analysis efforts by the NSWC/WO TDM.

2.3.2 Task 2 Conclusions and Recommendations

Because of the lack of current Lockheed-Georgia cost estimates, the expected major design changes, and the termination of our final cost analysis efforts, complete and accurate cost estimates are unavailable for the CAML system. We recommend that a dedicated cost analysis effort be initiated promptly during CAML FSED. Significant cost savings can be realized because of the redundant modular CAML design, and the cost analysis will be extremely useful for selection of a final CAML design.

Table 2-1. 15 MAY 1979 CAML PRODUCTION CONFIGURATION COST (INDIVIDUAL PALLET - SPECO DRIVE SYSTEM ONLY)

Component (SPECO Drawing No. and Acronym)	Recurring Unit Cost (Dollars*)	Launch Pallet		Ejector		C/P Pallet		Cradle	
		Quantity	Cost (Dollars*)	Quantity	Cost (Dollars*)	Quantity	Cost (Dollars*)	Quantity	Cost (Dollars*)
LGA 847 39-11 PDU Pallet (101)	5,783					6	34,698		
LGA 847 40-11 PDU (117 or 118)	4,857			6	29,142				
LGA 847 41-11 Drive G/B (105, 107, 109)	2,5[illegible]	4	10,324						
LGA 847 41-11 Drive G/B w/clutch (106, 107, 109)	2,663	2	5,326						
LGA 847 42-12 Drive G/B w/clutch (9, 19, 21, or 9, 20, 21)	2,663			24	63,912				
LGA 847 43-1 T.T. (111)	243			27	6,561				
LGA 847 43-2 T.T. (113)	295			9	2,655				
LGA 847 43-3 T.T. (115)	255	3	765						
LGA 847 43-4 T.T. (125)	298	3	894						
LGA 847 43-6 T.T. (137)	338	3	1,014						
LGA 847 44-1 Shaft Support (127)	40	3	120						
LGA 847 49-7 Rack, 60 inches (131)	204							1	204
LGA 847 49-3 Rack, 60 inches (modified) (129)	226							1	226
Total Cost			18,443		102,270		34,698		430
Pallet Stack Cost (3 Individual Pallets)			55,329		---		---		---

*Costs shown are in 1980 dollars.

Table 2-2. 23 JULY 1980 CAML PRODUCTION CONFIGURATION COST (MODULAR PALLET - SPECO DRIVE SYSTEM ONLY)

Component (SPECO Drawing No. and Acronym)	Recurring Unit Cost (Dollars*)	Launch Pallet		Ejector		C/P Pallet		Cradle	
		Quantity	Cost (Dollars*)	Quantity	Cost (Dollars*)	Quantity	Cost (Dollars*)	Quantity	Cost (Dollars*)
CAML 400-103 PD G/B	9,095					9	81,855		
CAML 400-105 P_L G/B (L)	8,017	6	48,102						
CAML 400-106 P_L G/B (R)	6,062	6	36,372						
CAML 400-107 P_L D Pinion	6,050	18	108,900						
CAML 400-109 U Joint	260	18	4,680	15	3,900				
CAML 400-111 T.T.	3,712	9	33,408						
CAML 400-113 T.T.	3,311	9	29,799						
CAML 400-121 E_j Pin	5,954			15	89,310				
CAML 400-127 SPT T.T.	346	9	3,114						
CAML 400-129 Rack Taper	497							1	497
CAML 400-131 Rack	462							1	462
CAML 400-135 Adapter	546	9	4,914						
CAML 400-137 T.T.	1,356					9	12,204		
CAML 400-141 T.T.	1,120	9	10,080						
CAML 400-143 Fairlead	638	18	11,484						
CAML 400-145 E_j G/B (L)	16,000			3	48,000				
CAML 400-146 E_j G/B (R)	16,000			3	48,000				
CAML 400-148 E_j E G/B	20,336			3	61,008				
CAML 400-151 EM D PN	5,661			3	16,983				
CAML 400-153 EM D SHF	1,661			3	4,983				
Total Cost (1 Modular Pallet)			290,853		272,184		94,059		959

*Costs shown are in 1980 dollars.

2.4 TASK 3: EVALUATE R&M AND LCC ASPECTS OF THE CAML SYSTEM DESIGN

In Task 3 we evaluated the CAML design from the standpoint of reliability, maintainability, and cost factors. Specific activities, results, conclusions, and recommendations for Task 3 are discussed in the following sections.

2.4.1 Task 3 Activities and Results

During May 1980 we assisted NSWC/WO in the development of the CAML Stockpile-To-Target-Sequence document. This document defines general actions required for major mission phases at various sites, from storage to delivery and return to storage, and it identifies maintenance functions, responsibilities, and requirements. Probable quantitative maintainability requirements, beyond those currently specified for the advanced development phase, are also identified for consideration in FSED specifications.

During May 1980 we also assisted in the development of the CAML Preliminary Maintenance Concept document. This document, developed in phase with the CAML Stockpile-To-Target-Sequence document, defines the maintenance responsibilities at all levels (organizational, intermediate, and depot) for the typical sites identified in the sequence. Air Force and Navy responsibilities are still being discussed and are not defined precisely at this time.

On 16 May 1980 we participated in discussions of the maintenance and maintainability requirements at a CAML ILS Meeting at NSWC/WO.

During June 1980 we briefly reviewed the Navy's CAML Acquisition Plan at NSWC/WO. On the basis of our review, some changes were made to the plan to accurately reflect existing CAML R&M requirements.

During June 1980 we also completed and submitted an evaluation of the modular pallet configuration proposed by Lockheed-Georgia to replace the originally planned individual pallet configuration. Efforts were directed toward identifying and evaluating the life-cycle-cost implications of the new concept. The costs of the individual and modular pallets were compared for both cast and welded construction configurations. In general, significant life-cycle-cost savings are realized by using the modular pallet concept (see Tables 2-1 and 2-2). In addition, there are possible operational advantages because of weight savings that extend aircraft range or payload. The evaluation of the modular pallet configuration is included in Appendix D.

In addition, during June 1980 it was determined that significant cost growth had occurred in the drive system proposed by SPECO. ARINC Research conducted an analysis of the pallet gearbox, the most expensive drive system component, to determine the cost drivers. Three gearbox parts, the bevel pinion, housing, and bevel gear, accounted for 65 percent of the gearbox cost. These costs resulted from high manufacturing labor hours. It was estimated that an average of 13 to 18 man-hours were required to fabricate or machine each part. Our evaluation was discussed at meetings with NSWC/WO.

We participated in CAML meetings at Lockheed-Georgia on 22 and 23 July 1980. The agendas included a preliminary design review of the CAML control system. Also included was a review of the progress of the CAML reliability and maintainability predictions. We reported the status of Lockheed-Georgia's R&M predictions to NSWC/WO during meetings at NSWC/WO on 24 and 29 July 1980.

During August 1980 we reviewed revisions to the CAML Maintenance Concept and the Stockpile-to-Target-Sequence (STS) documents prepared by the Naval Mine Engineering Facility (NMEF). We discussed our comments on the NMEF revisions with NSWC/WO, Code U32, on 13 August 1980. In general, NMEF had to make assumptions concerning the Navy/Air Force responsibilities at the aircraft loading site. Navy/Air Force responsibilities, as well as intermediate-level and organizational-level responsibilities, are not yet defined; they should be determined as soon as possible to facilitate maintenance and ILS planning. Although NMEF identified a requirement for special test equipment at the aircraft loading site, Lockheed-Georgia had not included this requirement on support equipment lists. In addition, NMEF did not identify a requirement for functional tests when a CAML system is removed from storage if it has been tested within one year of the removal. In our opinion, it will be desirable to perform functional tests on all CAML systems that are removed from storage for operational use.

Early in September 1980 we again reviewed the status of the CAML reliability prediction, maintainability prediction, and Failure Mode, Effects, and Criticality Analysis (FMECA) with Lockheed-Georgia. The purpose of this review was to identify problem areas early and to provide sufficient information for discussions at the CAML Design Review scheduled for 23 and 24 September 1980. On 8 September 1980 we visited Lockheed-Georgia to review progress in these areas. In general, progress was approximately one month behind the original schedule. Delivery of the Lockheed-Georgia reports to the Navy was not expected until late October 1980. The reliability and maintainability predictions showed that operational requirements would be met but that the overall CAML reliability, including storage-mode reliability, would not be met. Revised estimates of failure rates, higher than originally predicted, exceeded the allotted CAML storage reliability. However, the revised estimated storage reliability was close to the allotted reliability, and improvements in CAML components or refinement of the prediction may alleviate the problem. The FMECA was not sufficiently complete to permit our assessing at the meeting. The meeting with Lockheed-Georgia was reviewed with Navy R&M personnel on 9 September 1980 at NSWC/WO and documented in ARINC Research letter SEP/S&O/80-125 dated 24 September 1980.

We participated in the formal CAML Design Review held at NSWC/WO on 23 and 24 September 1980, providing assistance in reliability, maintainability, life-cycle-cost, and design-to-cost areas. We discussed the results of the design review with cognizant NSWC/WO personnel on 26 September 1980. The design review indicated that all R&M requirements could be met if the design was properly implemented.

In addition, during September 1980, we investigated possible reductions in costs associated with the design of the Ground Test Stand (GTS). Suggestions for cost reduction were informally presented to personnel at NSWC/WO. The three areas we evaluated were (1) reduction of the GTS height above the ground, (2) separation of the launcher and catcher sections, and (3) simplification of the catcher operation. It was determined that the recommended changes could result in cost savings, but only at the expense of a schedule delay.

During October 1980 we completed documentation of our comments on the CAML Design Review held at NSWC/WO on 23 and 24 September 1980. These comments were forwarded to the NSWC/WO by ARINC Research letter SEP/S&O/80-129 dated 15 October 1980.

In October we also started an investigation of various methods to demonstrate conformance to the CAML reliability requirements. To limit the reliability demonstration to an affordable expenditure of funds and time, the following alternatives were investigated: (1) simplification of the reliability requirement, (2) separation of the CAML system into individual test elements, (3) development of alternative test beds, and (4) development of alternative test methods. These approaches were discussed with NSWC/WO during a meeting at White Oak on 31 October 1980 and at subsequent meetings.

We attended the CAML ILSMT review at NSWC on 20 November, providing input to R&M and LCC areas.

On 18 March 1981 we attended a Lockheed-Georgia presentation at NSWC/WO to gather information on alternative CAML designs. The most promising alternative design concepts offer significant improvement in reliability and cost because they significantly simplify the system. In May we participated in a series of discussions on alternative CAML design concepts and the reliability impact of the CAML self-test capability with cognizant NSWC/WO personnel.

In July 1981 we investigated the effect of CAML self-test circuitry on overall reliability. The additional circuitry required to provide self-test capability is negligible when compared with the entire design. The resultant increase in CAML failure rate is negligible. Our findings were discussed with cognizant NSWC/WO personnel on 24 July.

On 18 August 1981, with cognizant NSWC/WO personnel, we witnessed the installation of the first CAML system in a C-130 at Lockheed-Georgia. By observing the operation, we developed an understanding of the problems inherent in handling and installing a system of this magnitude. However, observed logistic times were not relevant because of the inexperience of the loading crew and a defective K loader. The system was successfully installed after several mistrials caused by misalignment between the K loader and the aircraft. Problems observed were neither serious nor related to the CAML design in general. Our observations were discussed with cognizant NSWC/WO personnel in a meeting on 25 August.

2.4.2 Task 3 Conclusions and Recommendations

On the basis of our investigations, we conclude that the present CAML ADM design is capable of meeting specified R&M requirements with the exception of storage reliability. Storage reliability is marginal but is not considered a serious problem. However, the CAML system has exhibited considerable cost growth over the original Lockheed-Georgia proposal estimates. The alternative design concepts recently proposed by Lockheed-Georgia offer significant improvement in R&M and LCC areas. We recommend that Lockheed-Georgia's alternative design concepts be seriously considered, because simplification in the final CAML design can promote reliability, maintainability, and cost benefits.

2.5 TASK 4: DEVELOP RELIABILITY, MAINTAINABILITY, AND COST ANALYSIS REQUIREMENTS FOR FULL-SCALE ENGINEERING DEVELOPMENT

In Task 4 we developed and proposed R&M and LCC requirements for inclusion in NSWC/WO's CAML FSED Experimental Weapons Specification (XWS), Statement of Work (SCW), Work Breakdown Structure (WBS), and other Navy control documents. Specific activities, results, conclusions, and recommendations for Task 4 are discussed in the following sections.

2.5.1 Task 4 Activities and Results

In August 1980 we assisted NSWC/WO during review of the preliminary CAML WBS documentation that was prepared by PMS-407 to support the CAML Engineering Development Request for Proposal (RFP). Our R&M comments were provided to the Navy in a meeting at NSWC/WO on 16 September 1980. We recommended elimination of certain redundant data requirements for the R&M predictions and the addition of individual R&M test reports and test procedures. These changes affect RFP Sections 4, CAML System Test and Evaluation, and Section 6, CAML System Data. In addition, we recommended that Section 2, CAML System Support Equipment, be modified to require R&M-related tasks only on CAML-unique test equipment. Other changes were recommended to clarify the level and intent of CAML R&M tasks.

We also reviewed the preliminary FSED CAML WBS for cost implications. Specific recommendations are documented in Quarterly Status Letter No. 2.* Additional cost recommendations and revisions are documented in Quarterly Status Letter No. 3.**

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*ARINC Research letter SEP/S&O/80-136, 15 October 1980.
**ARINC Research letter SEP/S&O/81-015, 15 January 1981.

From October 1980 through January 1981, we assisted in developing the reliability and maintainability sections of the CAML XWS. In a series of meetings at NSWC/WO, we provided suggestions for revising the R&M program requirements.

On 11 December 1980, we participated in a meeting at NSWC/WO to clarify CAML reliability requirements and demonstration methods for the FSED reliability demonstration test. PMS-407, NSWC/WO, and Lockheed-Georgia personnel were present at this meeting. A definition of CAML mission success for reliability testing was developed. This definition simplifies the previous advanced development definition and will considerably reduce test time while preserving the intent of the advanced development definition.

On 28 January 1981 we participated in a meeting at Lockheed-Georgia to define CAML System FSED R&M requirements that are feasible and practical to demonstrate. In addition, CAML special test set requirements were discussed, but the need for CAML special test equipment was not conclusively established. However, tentative test equipment R&M requirements were identified in the event that the need is established.

In January and February 1981, in a series of working sessions and meetings at NSWC/WO, we provided R&M and LCC assistance during the development of updated versions of the CAML XWS and WBS documents. Both documents were considered ready for formal NSWC/WO review.

From July through August 1981, we continued to assist NSWC/WO in developing the final FSED CAML XWS by recommending minor revisions to the specification in areas of reliability and maintainability. The recommended inputs were provided and discussed during several meetings at NSWC/WO in August.

Late in November 1981, we started to review the CAML FSED Statement of Work (SOW). This review was completed in coordination with cognizant NSWC/WO personnel, and we provided recommendations to NSWC/WO in December 1981, as directed by the TDM.

2.5.2 Task 4 Conclusions and Recommendations

As a result of coordinated effort by the Navy, Lockheed-Georgia, and ARINC Research, the current ADM CAML design FSED requirements are adequately defined and documented. Unfortunately, because of expected major design changes and existing program funding constraints, significant changes to the requirements and documents may be required.

When a firm CAML design is selected and FSED development is funded, concentrated effort may be required to revise control documents in a short period. To minimize the document development time, we recommend that if program funding is restored, Navy personnel who have participated in or are familiar with earlier CAML efforts be assigned to future FSED efforts and associated preparation activities.

APPENDIX A

CAML MILESTONE REPORTS

This appendix presents three milestone reports representing Data Item A001 of Contract N60921-80-C-0155. The three previously delivered Milestone Reports document our review of certain Lockheed-Georgia deliverable data items under Contract N60921-80-C-0023 as follows:

- Milestone Report, ARINC Research letter serial SEP/S&O/80-084 of July 21, 1980
  - A012 - Report LG80ER0079, Reliability and Maintainability Allocation, Assessments, and Analysis, dated 28 April 1980, and revised report dated 12 June 1980

    A021 - Report LG80ER0031, Reliability, Maintainability and Safety Program Plan, dated 29 January 1980, revised 28 March 1980
  - A028 - Monthly Technical Progress Reports, dated April and May 1980
- Milestone Report, ARINC Research letter serial SEP/S&O/80-106 of August 11, 1980
  - A028 - Monthly Technical Progress Report, dated June 1980
- Milestone Report ARINC Research letter serial SEP/S&O/80-148 of December 4, 1980
  - A013 - Report LG80ER0176, Maintainability Analysis and Prediction, dated 15 October 1980
  - A019 - Report LG80ER0172, Reliability Prediction, dated 10 October 1980
  - A028 - Monthly Technical Progress Reports, dated July, August, September, and October 1980

CARGO AIRCRAFT MINELAYING (CAML) SYSTEM
MILESTONE REPORT
CONTRACT N60921-80-C-0155
CDRL ITEM A001

JULY 1980

The following are comments resulting from a review of Lockheed-Georgia deliverables under Contract N60921-80-C-0023.

1. LOCKHEED-GEORGIA REPORT LG80ER0079, DATA ITEM A012

Reliability and Maintainability Allocations, Assessments, and Analysis, 28 April 1980.

In defining mission success requirements, the allocation does not consistently address the operational reliability requirement correctly. Statements within the allocation are misleading, and the launch success criteria used in Appendix A to calculate subsystem success is incorrect.

The definitions of many Appendix A subsystem success criteria need further explanation (e.g., the resulting numeric values associated with individual subsystem success). Specific comments are as follows:

<u>Section 1.0, Page 1, Second Paragraph</u> - This paragraph may be interpreted to mean that there are no maintainability allocations, assessments, and analyses required in other deliverables of the Lockheed-Georgia contract. The comment is correct only in reference to data item A012.

<u>Section 3.0, Page 3, First Paragraph</u> - This paragraph is misleading and incorrect.

<u>Section 3.0, Page 3, Fourth Paragraph</u> - There should be no minus signs in the first two expressions for R_S.

<u>Section 5.0, Page 11, Table of Subsystem Percent of Total Failures Allowed/Sortie</u> - The hydraulic system failure rate allocation appears to be low. An explanation is desirable.

<u>Section 6.0, Page 14, First Paragraph, Last Sentence</u> - The implication that all failures will be discovered is not correct.

Appendix A, Page A-2, Criteria - The stated 209 successful launches does not meet the established reliability requirement. In addition, according to the stated criteria, a single sortie can pass with 21 successful launches, but the system will not pass if two of the required sorties eject only 23 mines successfully. In general, the system success criteria stated here is incorrect if the intent is to address operational reliability (R_{OPT}) and the associated launch percentages.

Appendix A, Page A-3, Mine Cradle Structure, Second Sentence - Lockheed-Georgia should provide an explanation.

Appendix A, A-4, Pallet Drive, Second Sentence - Lockheed-Georgia should provide an explanation.

Appendix A, Page A-4, Ejector Drive, First Sentence - 8" or 9" should be "8 of 9." Lockheed-Georgia should provide an explanation in the second sentence.

Appendix A, Page A-5, Pallet Drive Hydraulic Subsystem - An explanation of all three success criteria is required.

Appendix A, Page A-5, Ejector Drive Hydraulic Subsystem, First Statement - Lockheed-Georgia should provide an explanation.

Appendix A, Page A-6, Instrumentation Group, Second Statement - Lockheed-Georgia should provide an explanation.

2. LOCKHEED-GEORGIA REPORT LG80ER0079, DATA ITEM A012

Reliability and Maintainability Allocations, Assessments, and Analysis - Revision 1, dated 12 June 1980

The revised Lockheed-Georgia document is considered acceptable. The revised document demonstrates that the contractor now has an understanding of the reliability requirements. The requirements are now correctly stated in the report.

Appendix A of the previous version of the report, which contained incorrect and misleading statements, has been deleted. This is satisfactory, since Appendix A is not necessary to meet the data item contractual requirements.

The document still contains a statement in the second paragraph of page one that can be interpreted to mean there are no contractual requirements for CAML maintainability analysis. The statement is only correct within the context of this data item. The Navy approval letter should contain clarification restricting the acceptability of the statement to only this data item.

3. LOCKHEED-GEORGIA REPORT LG80ER0031, DATA ITEM A021

Reliability, Maintainability, and Safety Program Plan, 29 January 1980, Revised 28 March 1980

The plan is considered acceptable provided that the following change is incorporated in the plan.

In Figure 3-2, Maintainability Milestone Chart, the schedule submittal date of the Maintainability Analysis and Prediction Report (data item A013) is incorrect. Lockheed-Georgia agreed earlier to change the scheduled submittal from 180 days after contract award to 270 days after contract award. This change is desirable to allow the use of results from reliability reports (Failure Mode, Effects, and Criticality Analysis and the Reliability Prediction) in the maintainability prediction. The reliability reports are reasonably scheduled for late September 1980, and the Maintainability Analysis and Prediction Report should be scheduled concurrently.

4. LOCKHEED-GEORGIA MONTHLY TECHNICAL PROGRESS REPORT, DATA ITEM A028 April and May 1980

Both the April and May 1980 Lockheed-Georgia progress reports are acceptable in content and coverage of reliability and maintainability events. Reliability and maintainability progress is considered satisfactory.

Attachment B of the Lockheed-Georgia April Monthly Status Report, Modular Pallet Evaluation, discusses some of the life-cycle costs associated with changing from an individual pallet to a modular pallet for the mine launcher. Cost differences are identified for:

Pallet Structure

Loading Platforms

Pallet Slings

The costs of the pallet structure for both the cast and welded versions are identified on Page 4. These costs do not include an allowance for profit. A 15-percent fee should be added to these costs to be compatible with estimated CAML acquisition costs, which include profit. When the pallet costs were used in the table on page 8, math errors resulted in incorrect numbers.

Seven, not six, delivery sites are being considered; therefore, 28 platforms and 14 slings are required. The costs shown on page 9 should be adjusted accordingly.

A more detailed discussion of the life-cycle-cost impact was prepared for NSWC/WO and is included in ARINC Research's First Quarterly Status Report that was submitted to NSWC/WO, Code U-32, in July 1980.

CARGO AIRCRAFT MINELAYING (CAML) SYSTEM
MILESTONE REPORT
CONTRACT N60921-80-C-0155
CDRL ITEM A001

AUGUST 1980

The following comments resulted from a review of a Lockheed-Georgia deliverable under Contract N60921-80-C-0023. The deliverable reviewed is the Lockheed-Georgia Monthly Technical Progress Report, dated June 1980 (Data Item A028).

1. R&M REVIEW

The June progress report is acceptable in content and coverage of reliability and maintainability events. Reliability and maintainability progress is satisfactory.

The June progress report includes a complete listing of support equipment for both advanced development testing and operational requirements. A test set is identified, Control Test Set - CAML 434, that may require calibration at a scheduled interval. This will be of interest to ILS planners.

The progress report also includes a partial maintenance analysis of replaceable items. The drive system and the control system, which in combination will quite likely require the majority of maintenance actions, are not included. None of the analyzed maintenance actions pose a problem concerning contractual maintainability requirements.

2. PRODUCTION COST REVIEW

The June progress report is acceptable in content and coverage of cost events. We are reviewing the Lockheed-Georgia report on the SPECO drive system cost proposal, and the results of our review will be reported in our October 1980 Quarterly Status Letter.

CARGO AIRCRAFT MINELAYING (CAML) SYSTEM
MILESTONE REPORT
CONTRACT N60921-80-C-0155
CDRL ITEM A001

DECEMBER 1980

The following are comments resulting from a review of Lockheed-Georgia deliverables under Contract N60921-80-C-0023.

1. LOCKHEED-GEORGIA REPORT LG80ER0176, DATA ITEM A013

Maintainability Analysis and Prediction, 15 October 1980

1.1 General Comments

The report provides estimated maintainability parameters for the present CAML configuration. It is recommended that the report be conditionally accepted with the provision that it be revised to reflect any future updated configurations in the April through June 1981 time period. In addition, the revised maintainability prediction should correct the deficiencies identified in the specific comments that follow.

1.2 Specific Comments

Section 2.0, Page 4, Last Paragraph - The failure rate for storage (λ_s) should be presented in failures per million hours, not per five-year interval as stated. The stated failure rates in the maintainability prediction are derived from the reliability prediction. In some cases, the failure rates differ between the respective predictions because different data periods were used for the calculations. The maintainability prediction failure rates should be revised to coincide with the reliability prediction failure rates.

Section 3.4.2, Page 6, Entire Section - The presentation of CAML maintainability requirements is confusing and the units of measurement are not consistent in all instances. The entire section should be revised to comply with NSWC/WO CAML requirement definitions.

Table, CAML Support Equipment - Peculiar - The table should identify the mission profile sites that require support equipment and the quantity of equipment required per site.

Appendix B, Maintenance Task Analyses - The analyses and summary contain column-labeling errors, calculation errors, and possible configuration errors. The entire section should be checked for accuracy in the next revision of the maintainability prediction.

2. LOCKHEED-GEORGIA REPORT LG80ER0172, DATA ITEM A019

Reliability Prediction, 10 October 1980

2.1 General Comments

The report provides estimated reliability parameters for the present CAML configuration. It is recommended that the report be conditionally accepted with the provision that it be revised to reflect any future updated configurations in the April through June 1981 time period. In addition, the revised reliability prediction should correct the deficiencies identified in the specific comments that follow.

2.2 Specific Comments

Section 3.0, Page 4, Subsystem Failure or Malfunction - The entire subsection requires clarification of purpose and meaning.

Section 3.0, Page 4, Statement of Success - The statement is confusing and should be revised.

Section 6.0, Reliability Block Diagrams - The block diagrams should be based on procurable and maintainable elements. The chosen elements should be identified by CAML drawing numbers if available.

Appendix, CAML Failure Rate Calculation Sheets - The report states in Section 7.1 that calculations are based on an 85°C ambient temperature. However, this temperature is not used consistently throughout the prediction. In some cases 95°C was used for failure rate calculations. The calculations should be made consistent, or an explanation for deviations should be provided.

3. LOCKHEED-GEORGIA MONTHLY TECHNICAL PROGRESS REPORTS, DATA ITEM A028

July, August, September, and October 1980.

3.1 General Comments

The progress reports are acceptable in content and coverage of reliability, maintainability, and cost events.

3.2 Specific Comments

July, Appendix D - The failure of the Arming Plate Assembly that occurred during preliminary tests in July was not considered a serious problem at the time. The failure occurred after repeated use, and actual operational use will require only a single actuation. In addition, Lockheed-Georgia took remedial action to reduce the probability of the failure and completed a three-run retest with no failures.

July, Sections 2.1 and 3.3.2, SPECO Drive System - We recently compared the SPECO Drive System proposed on 15 May 1979 with the SPECO system proposed on 23 July 1980 (present configuration). The results of this comparison show a significant increase (more than 100%) in advanced development (ADM) cost that may ultimately be reflected in a higher CAML production cost. An effort has been initiated by Lockheed-Georgia to develop average unit-recurring-production costs for the SPECO parts. Certain costs should decrease because of a larger production volume and the effects of learning. Also, the anticipated use of numerically controlled equipment for the production contract by SPECO will reduce the required man-hours and the resulting cost. However, it is believed at this time that significant cost increases are occurring in the SPECO hardware that could adversely affect the CAML production contract costs. It is important that this area be monitored to control or reduce costs.

August, Section 3.6.9, Page 10, First Sentence - The failure of Arming Plate Assemblies during the trajectory tests at Eglin Air Force Base indicate the present design is unsatisfactory, since the failures occurred during conditions similar to operational use. A redesign of the Arming Plate Assembly is necessary and should be monitored by Lockheed-Georgia reliability personnel. Progress toward solution of the problem should be reported by Lockheed-Georgia in future progress reports.

September, Section 3.6.7.1, Page 11, Second Sentence - Lockheed reports that SPECO has submitted a rack and pinion endurance test plan for approval. There is a possibility that this test could contribute to a reliability demonstration of the CAML system for the areas tested. At a minimum, a discussion of this possibility is warranted.

October, Sections 3.6.2 and 3.6.7.3 - It is interesting to note that the Failure Mode, Effects, and Criticality Analysis (FMECA) has resulted in several design changes, including the deletion of 17 hydraulic/pneumatic pressure switches. This indicates that the CAML FMECA is fulfilling its intended function of design improvement.

APPENDIX B

REVIEW COMMENTS EXTRACTED FROM ARINC RESEARCH CORPORATION QUARTERLY STATUS LETTERS

The following material presents significant comments resulting from our review of certain Lockheed-Georgia data items delivered under Contract N60921-80-C-0023. The material was extracted from ARINC Research Corporation Quarterly Status Letters No. 4, SEP/S&O/81-047 of April 23, 1981; No. 5, SEP/S&O/81-087 of July 20, 1981; and No. 6, SEP/S&O/81-114 of October 15, 1981.

1. LOCKHEED-GEORGIA REPORT LG81ER0067, DATA ITEM A018

Failure Mode, Effects, and Criticality Analysis, 17 December 1980

1.1 General Comments

The Failure Mode, Effects, and Criticality Analysis (FMECA) is considered acceptable and is in general compliance with Data Item Description DI-R-2115A.

1.2 Specific Comments

As pointed out in the Criticality Matrix (Figure 6) and in Section 8.0, Criticality Matrix, the primary and emergency system microcomputers are the most sensitive elements of the CAML system. Between now and final production, continued efforts should be made in these areas to reduce failure rates through improved components or to reduce failure effects through increased redundancy.

2. LOCKHEED-GEORGIA MONTHLY TECHNICAL PROGRESS REPORTS, DATA ITEM A028

2.1 General Comments

The progress reports adequately address reliability, maintainability, and cost events.

2.2 Specific Comments

November, Section 3.6.4, 3rd Paragraph, Page 7 - The maintenance time goals, as stated, are inaccurate; however, reissue of the CAML advanced development configuration maintenance prediction is considered superfluous because of the current program status.

December, Section 3.6.6, 2nd Paragraph - The recently proposed CAML design change will alter predicted reliability and maintainability parameters. Therefore, Lockheed-Georgia should estimate the effect of the proposed change on both the reliability and the maintainability predictions. Any significant effect in either area should be considered in the Navy's decision to accept or reject the new design concept. On the basis of the preliminary information presented in the technical progress report, a noticeable improvement in predicted reliability and a negligible change in predicted maintainability is expected.

December, Attachment C - Lockheed-Georgia previously reported in the November Monthly Technical Progress Report that "SPECO was requested to prepare a production cost estimate for the drive system, based on quantities and delivery schedules received from ARINC Research on 3 November. This is a new combination of lot sizes and quantities as compared to the production estimates that SPECO has been working with previously. Receipt of these production cost estimates is anticipated in December."

Attachment C provides the new production cost estimate for the SPECO drive system. These data were not, in general, developed by SPECO but were generated by Lockheed-Georgia using the SPECO advanced development (ADM) cost estimate dated 23 July 1980, modified by Lockheed-Georgia learning curves. It is understood that the learning curves consider the use of numerically controlled equipment as experienced by Lockheed-Georgia. A comparison of the new cost estimate (also modified by appropriate lot sizes) is made with a single SPECO-supplied production estimate for the first lot of each component, which is based on 90 percent of the materials cost and 65 percent of the labor costs from the SPECO ADM cost estimate dated 23 July 1980. It is our opinion that although the validity of some of the data may be suspect, it is satisfactory at this point for examining the impact of SPECO changes on the total CAML acquisition cost.

January - No specific comments.

February, Attachment A - Attachment A provides more detail on CAML support equipment requirements than previously supplied by Lockheed-Georgia. Item P3 provides justification and recommendation to develop a CAML control system test set. Additional justification should be requested by the Navy before a decision is made to fund the development of the special test set.

3. LOCKHEED-GEORGIA MONTHLY TECHNICAL PROGRESS REPORTS, DATA ITEM A028
March, April, and May 1981

The progress reports are considered acceptable.

4. LOCKHEED-GEORGIA MONTHLY TECHNICAL PROGRESS REPORTS, DATA ITEM A028
June and July 1981

The progress reports are considered acceptable.

APPENDIX C

REVIEW COMMENTS ON LOCKHEED-GEORGIA DATA ITEM A010 (RELIABILITY TEST PLAN) AND DATA ITEM A014 (RELIABILITY PROGRAM PLAN)

The following are comments resulting from our review of two Lockheed-Georgia documents delivered under Contract N60921-80-C-0023.

1. LOCKHEED-GEORGIA REPORT LG81ER0232, DATA ITEM A010

CAML System Full Scale Engineering Development Reliability Test Plan, 26 October 1981.

1.1 General Comments

The report basically follows the concept discussed with Lockheed-Georgia during meetings held at NSWC/WO and Lockheed-Georgia. However, deficiencies exist, thereby preventing a recommendation for acceptance without revision.

1.2 Specific Comments

There is no reference to a test procedure in the plan. A detailed procedure submitted approximately 90 to 120 days prior to the scheduled test is a necessity.

The test plan states that the system level test was negotiated with NSWC/WO. This is erroneous. The concept was agreed upon, but the entire system level test was not.

Maintenance during test is not adequately addressed. Normal maintenance should be defined and allowable. Abnormal maintenance to correct a degrading condition would constitute a failure under certain conditions. Tolerances for temperature, vibration, and voltage should be stated. Pretest "Burn-In" should be defined.

The procedures involved in verifying that a failure has been corrected should be defined. Repair verification time should not count as test time.

On Page 12, the plan states that the system level test presented in the plan is a fixed time test. It is not; it is a sequential cycle test. Lockheed-Georgia has a much greater chance of passing this test than a fixed time test with one prestated decision point.

2. LOCKHEED REPORT LG81ER0231, DATA ITEM A014

CAML System Full Scale Engineering Development Reliability Program Plan, 26 October 1981

2.1 General Comments

The report defines a good reliability program plan that is in basic accordance with MIL-STD-785. Basic deficiencies exist, however, preventing a recommendation for acceptance without revision.

2.2 Specific Comments

The plan is weak in defining the reliability analysis to be performed on the CAML system. The plan does not address required manpower budgeting or define the extent of identified personnel commitment to CAML FSED. The plan does not adequately address the interface between reliability, design, and other related design support organizations. The plan does not adequately address the planned transition from FSED to production.

APPENDIX D

COST ANALYSES

1. CAML ACQUISITION COST UPDATE

An ARINC Research report* on the estimated CAML acquisition cost was prepared for the CAML Program Office. After the report was published, Lockheed-Georgia conducted a more detailed evaluation of the labor required for the control/power pallet electrical fabrication. The estimated average man-hours per pallet was revised, decreasing from 3,295 to 1,418. This reduction in man-hours results in an eight percent reduction in the total CAML acquisition cost and also changes the ranking of cost drivers. The current estimated acquisition costs for each cost element are identified in Table D-1. They can be used to update the data in Tables S-1, 4-4, 4-6, and 5-1 of our previous report.

2. COST COMPARISON BETWEEN CAML MODULAR AND INDIVIDUAL PALLETS

In March 1980 Lockheed-Georgia proposed a change in the design of the CAML Launcher Pallet. The new concept consists of a modular pallet that can accommodate nine mines. Each modular pallet replaces three individual, vertically stacked pallets that hold three mines each. This change in the proposed technical approach is expected to alleviate significant technical problems.

We performed a cost analysis to consider the potential impact of the proposed design change on CAML life-cycle costs. The Lockheed-Georgia report, *Modular Pallet Evaluation,* by J. D. Stites, dated 30 April 1980, was used as a basis for our analysis.

2.1 Cost Analyses

We compared the acquisition costs of the individual and modular pallets for both cast and welded construction. Costs for labor and material for each structure were estimated by Lockheed-Georgia. Table D-2 summarizes total acquisition costs for the four configurations.

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*ARINC Research Publication 1672-02-1-2185, *An Analysis of the Preliminary Acquisition Cost of the Cargo Aircraft Minelaying (CAML) System (U)*, April 1980 (Confidential).

Table D-1. CAML COST DRIVERS (RANKED BY ACQUISITION COST)				
Cost Element	Component	Acquisition Cost (Dollars)	Percentage of CAML Acquisition Cost	Cumulative Percentage of CAML Acquisition Cost
SPECO Gear Box	Launcher Pallet	7,349,706	21.3	21.3
Material	Cradle	3,408,000	9.9	31.2
Hydraulic System	C&P Pallet	2,610,996	7.6	38.8
Material	Launcher Pallet	2,526,888	7.3	46.1
Labor (Fabrication and Assembly)	Cradle	2,286,000	6.6	52.7
Labor (Electrical Fabrication)	C&P Pallet	2,228,700	6.5	59.2
SPECO Gear Box	Ejector	1,831,818	5.3	64.5
Labor (Fabrication and Assembly)	Launcher Pallet	1,351,896	3.9	68.4
Electrical System	C&P Pallet	1,196,426	3.5	71.9
SPECO Rack	Cradle	1,164,000	3.4	75.3
SPECO Torque Tube	Launcher Pallet	1,089,816	3.2	78.5
SPECO Power Drive	C&P Pallet	984,164	2.8	81.3
Labor (Fabrication and Assembly)	C&P Pallet	955,298	2.8	84.1
Labor (Engineering, Tool, QA)	Cradle	864,000	2.5	86.6
SPECO Power Drive	Ejector	853,026	2.5	89.1
Labor (Fabrication and Assembly)	Ejector	828,988	2.4	91.5
Hydraulic System	Ejector	563,550	1.6	93.1
Labor (Engineering, Tool, QA)	C&P Pallet	348,772	1.0	94.1
Labor (Engineering, Tool, QA)	Ejector	301,342	0.9	95.0
Labor (Engineering, Tool, QA)	Launcher Pallet	289,926	0.8	95.8
Material	Ejector	269,790	0.8	96.6
SPECO Torque Tube	Ejector	267,784	0.8	97.4
Nonrecurring Cost	Launcher Pallet	193,830	0.6	98.0
Material	C&P Pallet	173,910	0.5	98.5
Nonrecurring Cost	Cradle	162,000	0.5	99.0
Electrical System	Ejector	114,172	0.3	99.3
Nonrecurring Cost	Ejector	99,756	0.3	99.6
Nonrecurring Cost	C&P Pallet	82,518	0.2	99.8
SPECO Tube Support	Launcher Pallet	54,600	0.2	100.0
Total Cost		34,451,672		

Table D-2. TRANSPORT PALLET ACQUISITION COST

Cost Category	Individual Pallet Costs (Dollars)		Modular Pallet Costs (Dollars)	
	Cast Construction	Welded Construction	Cast Construction	Welded Construction
Recurring Cost				
Structure Labor and Material	7,635	18,400	24,150	32,200
Original SPECO Drive	15,557	15,557	46,671	46,671
Additional Fourth Pinion	4,487	4,487	N/A	N/A
Nonrecurring Cost				
Original Nonrecurring	355	355	1,065	1,065
Additional Nonrecurring	92	92	N/A	N/A
Total Cost per Pallet	28,126	38,891	71,886	79,936
Acquisition Cost, Including Pallets	15,356,796	21,234,486	13,083,252	14,548,352
Acquisition Cost Difference Compared with Individual Cast Pallet Configuration	0	+5,877,690	-2,273,544	-808,444

Because of alignment considerations, the individual pallet requires additional pinions that increase the cost. The individual pallet also requires an additional alignment jig for production that increases the nonrecurring costs by approximately $50,000, or $92 per pallet. The modular pallet is larger and heavier than the individual pallet and requires additional support equipment. Four loading platforms will be required at each delivery site. The estimated cost is $11,000 per platform. The heavier pallet load, about 17,000 pounds, will require a stronger, more expensive loading sling. Two slings will be required at each delivery site at an additional cost of approximately $1,000 per sling. It is expected that the available cranes will have the capacity to handle the heavier loads. The expected additional support equipment costs are shown in Table D-3. Tables D-2 and D-3 show that the acquisition and support costs of both the cast and welded modular pallets are less than the costs of either the cast or welded individual pallets.

Table D-3. ADDITIONAL SUPPORT EQUIPMENT COST FOR THE MODULAR CONCEPT

Support Equipment	Cost per Unit (Dollars)	Quantity per Delivery Site	Number of Delivery Sites	Additional Acquisition Cost (Dollars)
Loading Platform	11,000	4	7	308,000
Pallet Slings	1,000	2	7	14,000
Total				322,000

Some significant life-cycle-cost elements that are affected by adopting the modular pallet concept were identified, and cost estimates or descriptions of possible cost changes were developed for each cost element. The relevant life-cycle-cost elements and the potential cost impact for each are summarized in Table D-4. A complete life-cycle-cost comparison cannot yet be made.

The modular pallets have an additional operational advantage because of their reduced weight. Three individual welded pallets are estimated to weigh 5,760 pounds versus 3,990 pounds for a modular welded pallet. This weight reduction of 1,770 pounds per pallet stack will allow an increase in either fuel or cargo capacity. The additional range or number of additional CAPTOR mines that could be accommodated are shown in Table D-5. The weight reduction for the cast pallet was not evaluated because of insufficient data.

Life-Cycle-Cost Element	Relative Cost Implications			
	Individual Pallet		Modular Pallet	
	Cast Construction	Welded Construction	Cast Construction	Welded Construction
Research and Development				
Full-Scale Engineering Development				
Contractor and Government	Transfer Cost*		Transfer Cost*	
Investment				
Prime Equipment				
Production Hardware	$15,356,796	$21,234,486	$13,083,252	$14,548,352
Initial Support				
Initial Spares	More pinions to be supported**		Spare pallets more expensive	
Support Equipment				
Platform and Slings			$322,000	$322,000
15 to 20 Ton Crane			Heavy-lift crane required	
Operation and Support				
Operating				
Personnel	No identified difference			
Support				
Maintenance	a. More subject to damage† b. More maintenance required** c. Alignment jig required at IMA†			
Production Hardware Cost Difference (Compared with Individual Cast Pallet Configuration)	0	+$5,877,690	-$1,951,544	-$486,444

Table D-4. COST COMPARISON BETWEEN INDIVIDUAL AND MODULAR PALLET

*The initial pallet will be a welded design. If the production pallet is a cast design, then the required design changes may result in additional costs for design, test, evaluation, and documentation.

**A 33 percent increase in the number of pinions in the launcher pallet is expected to require an increase in the cost of spares and maintenance.

†The close tolerance interface between pallet tiers is expected to require additional maintenance and the use of an additional alignment jig.

Table D-5. WEIGHT REDUCTION PER AIRCRAFT					
Weight Reduction				Benefits of Weight Reduction	
Aircraft	Weight Reduction per Stack (Lbs.)	Pallet Stacks per Aircraft	Weight Reduction per Aircraft (Lbs.)	Additional Range Capability (nmi)	Additional CAPTOR Capability (2500 Lbs.)
C-130	1,770	2	3,540	~275	1.4
C-141	1,770	6	10,620	~425	4.2
C-5A	1,770	8	14,160	~350	5.7

3. CONCLUSIONS AND RECOMMENDATION

The modular pallet concept was initiated by Lockheed-Georgia because it can reduce the CAML design risk. This cost analysis shows that acquisition cost of the CAML hardware and support equipment will also be reduced. In addition, a reduction in maintenance cost is anticipated for the modular concept. Finally, the maximum fuel or cargo capacity will be increased by the modular concept.

As the modular design is refined, changes that affect the life-cycle cost will occur. We recommend that the modular pallet concept be pursued and that the life-cycle-cost implications be monitored as the design concept matures.

APPENDIX E

CARGO AIRCRAFT MINELAYING (CAML) SYSTEM
DESIGN REVIEW REPORT

This appendix reproduces ARINC Research Corporation letter report (serial SEP/S&O/80-129 of 15 October 1980) and represents Data Item A003 under Contract N60921-80-C-0155.

The following are ARINC Research comments resulting from the Lockheed-Georgia Design Review held at Naval Surface Weapons Center, White Oak (NSWC/WO), on 23 and 24 September 1980. These comments address reliability and maintainability (R&M) and life-cycle-cost (LCC) areas only, and unless otherwise noted represent ARINC Research judgments and opinions.

1. R&M REVIEW

The Lockheed-Georgia operational reliability prediction satisfies the CAML requirement. However, the combined storage and operational reliability prediction does not meet the combined requirement. At this time, the deficiency in the overall reliability requirement because of higher predicted storage failure rates is not considered to be a serious problem for the following reasons:

- The Lockheed-Georgia prediction is extremely conservative, and the overall predicted reliability is close to the minimum requirement.
- The operational reliability requirement is more important and requires demonstration.
- Historically, storage reliability requirements have been a goal and do not require demonstration.
- Preventive maintenance, protective packaging, and improved components can help to alleviate the storage reliability problem. However, this can affect life-cycle costs.

The Lockheed-Georgia maintainability prediction is not complete and therefore cannot be assessed. At the design review, the Lockheed-Georgia maintainability engineer reported that the two man-hour mean for intermediate-level maintenance may not be achieved. It is believed that the system could reach a three man-hour mean for repair. Further communication with Lockheed-Georgia's maintainability engineer on 26 September 1980 indicated that their estimate at the design review was overly pessimistic. Additional data indicate that the CAML system will meet the required two man-hour mean for intermediate-level maintenance. An additional maintainability requirement for intermediate-level maintenance, the requirement for a mean time to repair of one hour (MTTR = 1 hour), was not discussed at the design review.

Lockheed-Georgia has not addressed all assumptions (e.g., packaging in the storage mode) that relate to the maintainability prediction. Additional communication with Lockheed-Georgia by NSWC/WO and ARINC Research is advisable to assure that all necessary assumptions are included in the maintainability prediction.

SPECO tests of the torque tube pallet-to-pallet adapters will start shortly. The adapter is the connecting link between pallets, and installation of these adapters during aircraft loading must be a relatively simple, repetitive procedure that assures consistent, proper alignment. We recommend that Lockheed-Georgia personnel monitor these tests.

The C-141 aircraft modification, intended to provide compatibility with the CAML system, is unsatisfactory. The proposed modification involves splicing two wires into a wire bundle in the aircraft. Although an individual splice accomplished by trained personnel may be acceptable, achieving good electrical connections in a population of splices made under operational conditions by nonfactory personnel is unlikely. It is recommended that Lockheed-Georgia identify a more reliable method to modify C-141 aircraft.

Lockheed-Georgia estimates that two to four hours will be required for the Ground Test Stand (GTS) to recycle and launch successive test loads. This significant time requirement could affect the feasibility of demonstrating the present reliability requirement using the GTS. With the GTS used as the test bed, a reliability demonstration test that would demonstrate the present reliability requirement to a 90-percent confidence limit could require one to two years of testing. This requirement is based on the assumption that two test stand launches could be completed during a standard 8-hour workday. It is recommended that Lockheed identify an alternative test method.

2. ACQUISITION COST REVIEW

CAML production costs were not specifically addressed during the design review; however, some of the advanced development (ADM) design changes that were discussed will affect future production cost. In some cases, redesign of ADM hardware has increased estimated production costs and the resultant acquisition costs. The SPECO ADM hardware cost estimate has doubled since the May 1979 estimate. This impact on acquisition cost is expected to be substantial and should be quantified by Lockheed-Georgia and ARINC Research at the earliest opportunity.

In addition, other recent ADM system improvements will affect Lockheed-Georgia production costs. Lockheed-Georgia and ARINC Research should identify the cost impact of the following changes or additions and update the acquisition cost estimate:

- <u>Launcher</u>
  - Modular Design
  - Brake System
  - Lock System
- <u>Control/Power Pallet</u>
  - Brake System
  - Lock System
  - Increase in Computer Complexity
  - Increase in Control Complexity

- <u>Ejector</u>
  - Back-Up Ejector
  - Increase in Control Complexity
- <u>Cradle</u>
  - Lock System

3. CONCLUSIONS AND RECOMMENDATIONS

Coverage of CAML R&M areas at the design review was adequate, and progress in R&M is considered satisfactory. At this point, Lockheed-Georgia has demonstrated a conscientious effort to meet R&M requirements. It may not be possible to achieve some ADM requirements (e.g., storage failure rate), but at present there is no conclusive evidence that indicates R&M requirements cannot be met.

The design and preliminary tests of the SPECO mechanical drive should be actively monitored by Lockheed-Georgia R&M personnel. The CAML control system warrants further reliability analysis to investigate the possibilities of making it either more redundant or less complex.

The C-141 aircraft modification is unsatisfactory. Lockheed-Georgia should investigate an alternate method.

Use of the Ground Test Stand (GTS) to demonstrate the system reliability requirement will require too much time. It is recommended that Lockheed-Georgia identify an alternative test method.

The redesign of the ADM hardware will affect production costs and could significantly affect system acquisition costs. The effects of the redesign should be determined at the earliest opportunity by Lockheed-Georgia and ARINC Research.

APPENDIX F

RESOURCE EXPENDITURES FOR CONTRACT N60921-80-C-0155

Figure F-1 presents the cumulative funding and man-hour expenditures for Contract N60921-80-C-0155.

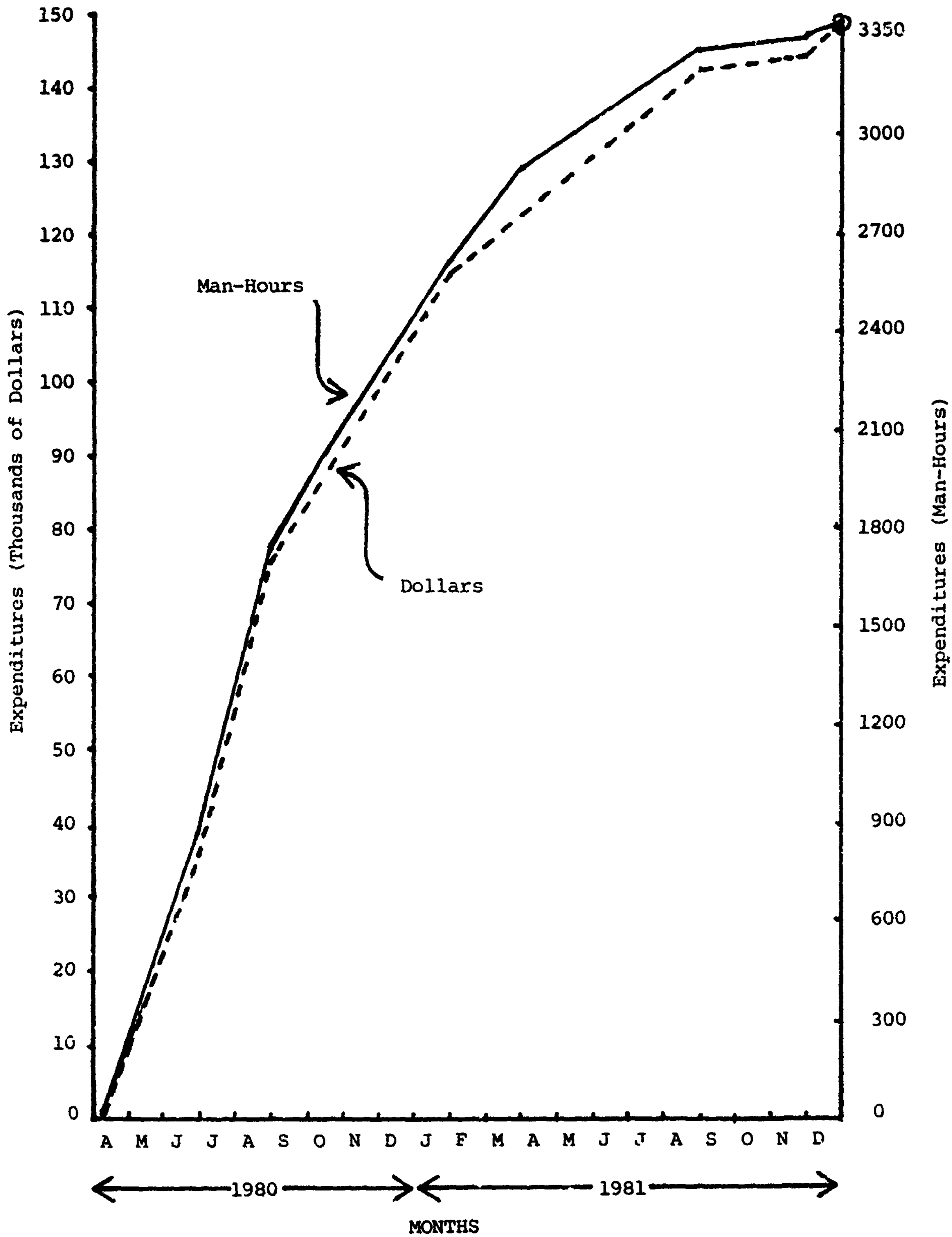

Figure F-1. CUMULATIVE FUNDING AND MAN-HOUR EXPENDITURES FOR CONTRACT N60921-80-C-0155